



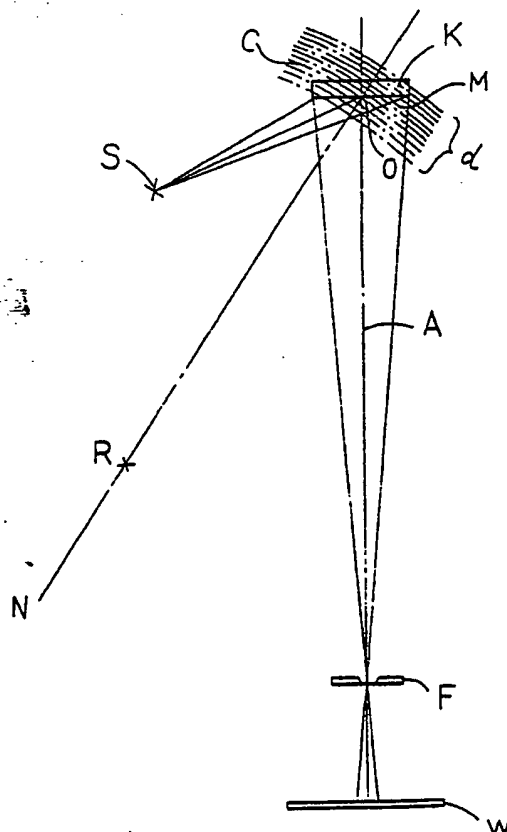
INTERNATIONAL APPLICATION PUBLISHED UNDER THE PATENT COOPERATION TREATY (PCT)

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(54) Title: X-RAY REFLECTIVE MASK AND SYSTEM FOR IMAGE FORMATION WITH USE OF THE SAME

(57) Abstract

X-ray lithography which has been applied, for instance, to reproduction of a pattern for integrated electronic circuit wherein the proximity method is prevailed with use of a transmissive patterned mask. But this conventional method is defective, for instance, in difficulty of dimensional reduction from an original pattern. In contrast, the disclosed invention overcomes such defect by introducing an X-ray reflective mask element, instead of conventional type of transmission. The reflective mask element is comprised of a crystalline substrate to reflect incident X-ray according to the Bragg's diffraction rule, which was worked out of a crystalline body having outwardly curved lattice surfaces, wherein the substrate face is formed to have an inclination against the lattice surfaces so that reflection at center of the substrate face will converge to a point on normal line assumed at the same center. Another aspect of the disclosure herein is directed to a system for X-ray projection and image formation with use of said mask element, additionally comprising an X-ray source, a Fresnel zone plate.



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DESCRIPTION

Title of the Invention

X-RAY REFLECTIVE MASK AND SYSTEM FOR IMAGE FORMATION

5 WITH USE OF THE SAME

Technical Field

This invention relates to a reflective mask element which will be suitably applied to submicron-level lithography by X-ray projection
10 and a system for image formation with use of the same.

Background Art

Conventionally, in the process of manufacture of LSI, optical lithography technology has normally been applied for reproduction
15 of a pattern drawn on a mask. But the optical lithography technology is commented to reach its patterning limit up to $0.5\mu\text{m}$ and besides, because of effect of Fresnel diffraction and shortness of focal distance, formation of a more compact pattern with less than $1\mu\text{m}$ requires introduction of a multi-layer resist and CEL process. On
20 account of such, the process involved becomes complicate and results in a low product yield, which leads to assessment that such a method will come to end in the near future. Probable replacing new methods are thought to be the direct drawing with electric beam and X-ray lithography. Wherein, the direct drawing with electric
25 beam is defective in throughput, accuracy of stage connection and inevitable introduction of multi-layer resist to attain a hight aspect ratio. In contrast, the X-ray lithography is based on image copy or transfer, for which it is advantageous to mass reproduction and it is also based on use of a ray having several angstroms to
30 several tens angstroms in wavelength, for which the effect of

1 undesirable diffraction may be disregarded in substance and resolution thereby is expected to reach up to 0.1 μm .

The X-ray lithography includes, simply classed, two methods. One
5 is a method that is presently prevailed, proximity method which comprises X-ray exposure in a proximate distance of about 10 μm between a mask and a wafer to transfer a pattern on the mask. Another one is X-ray projection and exposure method which transmits a pattern shadow to a wafer with aid of a X-ray imaging device.

10

Disclosure of the Invention

This invention is firstly concern with a mask element which is applied in the latter of the X-ray projection and exposure method. But the inventive mask element is different, as will be described in
15 detail below, from conventional masks of transmission type. And avoidance of that type comes from, briefly noted, that X-ray used normally in the X-ray lithography has several angstroms to several tens angstroms in wavelength or soft X-ray and impediment involved therein is that, because X-ray of such wave range is easy to be
20 absorbed by general materials, a mask substrate for such X-ray should be an extremely thinned membrane having several μm in thickness made of X-ray transmissive material, for instance, BN (boron nitride) and thereon conventionally a resist film is formed with a X-ray absorbent material, for instance, Au. On such account,
25 conventional transmissive masks are physically brittle or fragile, which brings a number of problems; difficulty in handling, easy deformation due to handling or heat, complicate in manufacture and resultantly such brings a proximity apparatus to be so expensive and difficult to operate.

30

1 This invention intends to offer a mask element which comprises a
X-ray absorbent patterned mask film coated on a X-ray reflective
substrate capable of focussing the reflected X-ray toward image
formation, and this also intends to offer a system for reproducing
5 a pattern image onto a target plate, including said mask plate, a
X-ray source and an image formation device and thereby this intends
to solve the problems attendant with the art based on conventional
transmission type masks.

The patterned mask element comprising a X-ray reflective substrate
10 in the present invention is summarized in that a substrate is a
plate which was cut out or worked out of a crystalline substance
having its original lattice surfaces for X-ray diffraction curved or
arched outwardly to effect converging function to reflecting X-ray,
wherein such a crystalline body is worked out by regulating an angle
15 assumed between curvature of lattice plates and a newly cut-out
substrate face so as to maintain a direction of X-ray in
conformity of Bragg's reflection (or diffraction) at center of the
substrate face to agree with normal line assumed at the same
center (hereinafter "Bragg's reflection or diffraction" will be
20 abbreviated to "Bragg"). And thereon a X-ray absorbent mask film
is formed and then patterned.

As for another aspect of the invention, namely, the system for
image formation with use of the mask element will be referred to in
subsequent paragraphs for embodiments.

25

Brief Description of the Drawings

Fig. 1 is a schematic diagram to show a substrate sectionally and
geometrical lines related to explain theoretical background or
support involved in the present invention. Fig. 2 is a schematic
30 diagram, not to scale, to show an embodiment of X-ray projection

1 and imaging system including the inventive mask element.

Mode(s) for Carrying Out the Invention

Summarized hereinbefore, this invention utilizes X-ray diffraction caused by lattice surfaces formed in curvature and necessity of such curvature will be briefly explained with reference to Fig. 2. Therein, X-ray radiated from a X-ray source S comes to be incident onto a mask element M (hereinafter M also represents a substrate face or mask film remnant on the substrate case by case) wherein X-ray portion incident directly onto substrate surface or pattern
10 lines, where X-ray absorbent mask film was removed previously, is diffracted by lattice surfaces inside the substrate, and then reflecting or diffracted X-ray should travel to converge onto a X-ray imaging device F and therethrough a mask pattern is imaged onto a wafer W.

15 In this optical system, in order for an image formed on the wafer to be an accurate reduced reproduction of a pattern on the mask element, optical axis A in this image formation system should be vertical to the mask plane (but not vertical to lattice surfaces),
20 which logically follows that the source S should not lie on the optical axis A. This logic leads to key requisite that reflecting X-ray at center O of the mask should travel coinciding with the optical axis A to reach the imaging device F. For attainment of this requisite, as Fig. 1 shows, a substrate plate is regulated in
25 working out so that lattice surfaces C in curved crystal structure should have an inclination against cut-out surface to satisfy with the requisite above, in other words, the substrate plate K has been so designed that, if suitably incident, diffracted X-ray at center of the plate K will travel to agree with normal line (substantially
30 A) assumed at the same center. Consequently, the present invention

- 1 allows to set the X-ray mask to face or to orient vertically to the optical axis A in the imaging system.

Proceeding to explanation of an embodiment shown in Fig. 1,
5 therein assumed is an outwardly curved lattice structure having a lattice constant d , and also assumed is a substrate plate which was worked out of the lattice structure of which curved lattice surfaces C are on circular lines with respect to a center point R_0 so that face of the substrate ($-L, 0, +L$) should cross lattice surfaces C
10 obliquely with a certain inclination to lattice surfaces retained.

O is center of the mask or substrate face, R is radius of curvature for curved lattice surfaces, i is an incident angle from the X-ray source S and F is a Fresnel zone plate (FZP), and X-ray of wavelength λ is assumed.

- 15 U, Q represent that X-ray starting from U and reflecting at $-L$ point (one end of the substrate) by Bragg will cross at Q with center X-ray which also starts from U to reflect at O point (center) by the same diffraction, then to follow optical axis A. Comparably, T, P represent that X-ray starting from T and reflecting
20 at $+L$ point (the other end thereof) by Bragg will cross at P with the same center X-ray. As will be understood, U and T lie on the same one line through O and the X-ray source S lies between T and U. On the other hand, P and Q lie on the other same line through O and the FZP F lies on between P and Q.

- 25 R_0 is curvature center for curved lattice surfaces C as noted above and J, N are end points of vertical lines drawn from $-L$ to a line OR_0 and to a line OU, which leads to that, because incident and reflective angles of X-ray at $-L$, $+L$ and O points are all equal (i) due to the nature of lattice structure and Bragg's rule, points O,
30 $-L$, U, R_0 , Q are found to lie on the same circle line r and that

1 points +L, O, T, R₀, P are also found to lie on the same circle line r'.

Then, X-ray of wavelength λ incident onto lattice surfaces C of
 5 lattice constant d with an incident angle i is subjected to follow Bragg, which is given below:

$$2d \times \cos i = \lambda \text{ (diffraction order = 1 is assumed) ... } \textcircled{1}$$

Diffraction X-ray in conformity with the above requirement is enhanced or added together only in the same angle direction i by
 10 which the X-ray takes on reflection in the direction of the angle i.

It is now assumed that the substrate plate K was worked out of a curved crystal structure having the curvature radius R as shown in Fig. 1, normal line (will be proved to be the same that A later) set
 15 at the center O of the substrate face renders an angle i with respect to normal line OR₀ set on the lattice surfaces, which follows that setting of the X-ray source S on a line OU symmetrically opposite to the normal line A with respect to the normal line OR₀ will allow the normal line (substantially A) set
 20 at the center of substrate face to agree with the diffracting direction of X-ray by Bragg $\textcircled{1}$, namely, optical axis A in imaging system (see Fig. 2).

Referring to optical lines in Fig 1, at the point -L away for W
 25 from the substrate center O, it is assumed that an angle between reflecting X-ray by the Bragg (-L to Q) and optical axis A is noted α . Then the angle α is equal to an angle formed between a normal line set at -L on lattice surfaces (-L to R₀) and a normal line set at O on the same (O to R₀), which follows:

$$30 \quad \tan \alpha = -LJ / R_0 J$$

$$1 \quad = W x \cos i / (R - W x \sin i) \dots\dots ②$$

$$OQ = W / \tan \alpha$$

$$= (R - W x \sin i) / \cos i \dots\dots\dots ③$$

$$OU = UN + NO$$

$$5 \quad = UL \cos \alpha + W x \sin 2i$$

$$= QL \cos 2i x \cos \alpha + W x \sin 2i$$

wherein $QL = OQ / \cos \alpha$, therefore

$$OU = \cos 2i (R - W x \sin i) / \cos i + W x \sin 2i$$

$$= (2R \cos^2 i + W x \sin i - R) / \cos i \dots\dots\dots ④$$

10 In similar way,

$$OP = (R + W x \sin i) / \cos i \dots\dots\dots ⑤$$

$$OT = \cos 2i (R + W x \sin i) / \cos i - W x \sin 2i$$

$$= (2R \cos^2 i - W x \sin i - R) / \cos i \dots\dots\dots ⑥$$

15 These geometrical derivations teach that two X-rays reflecting by Bragg at the points +L, -L come to cross the reflecting line (substantially A) from the center point O and that these cross points Q from -L and P from +L are deviated or departed and that this deviation is aberration caused by geometrical distance between
20 +L and -L. Then an intermediate point F may be assumed to counterbalance aberrations with both source and image sides at an equal value, which will be,

$$\pm W x \tan i \dots\dots\dots ⑦$$

Therefore, a X-ray imaging device may be placed on the optical axis
25 A at a point (substantially F) which is distant from the substrate K for a length noted below;

$$R / \cos i \dots\dots\dots ⑧$$

And a X-ray source S may be placed on a symmetrical line (substantially OU) opposite to the axis A with respect to the
30 normal line (OR₀) at the substrate center O against

- 1 lattice surfaces, at a point distant from the substrate center O for a length noted below;

$$(2R \times \cos^2 i - R) / \cos i \dots\dots\dots \textcircled{9}$$

A specific embodiment is given to prove numerical basis as below:

- 5 X-ray wavelength $\lambda = 5.406$ angstroms, and Ge (1 1 1) crystal surface having $d = 3.25$ angstroms and $i = 33.7$ degrees as curved crystalline structure and as substrate, size of $50 \text{ mm} \times 50 \text{ mm}$ and $W = \pm 25 \text{ mm}$, and distance from O point to F point = 600 mm are applied.

- 10 The following calculations are derived:

The curvature radius for curved crystal structure is by the formula $\textcircled{8}$;

$$R / \cos 33.7 = 600, \quad R = 600 \times \cos 33.7 = 499.2 \text{ mm}$$

The location (Y) of the source S is given by $\textcircled{9}$ assuming that the

- 15 source should be located to balance aberrations as noted;

$$\begin{aligned} Y &= (2R \times \cos^2 i - R) / \cos i \\ &= 277.2 \text{ mm} \end{aligned}$$

Maximum aberration = $2W \times \tan i$ is given;

$$\begin{aligned} 2W \times \tan i &= 2 \times 25 \times \tan 33.7 \\ &= 33.3 \text{ mm} \end{aligned}$$

20

- Practically the maximum aberration calculated is not significant and therefore it is acceptable to use such a curved crystal structure as noted to reflection and to imaging by X-ray, for which formation of the X-ray absorbent film thereon and subsequent
25 patterning are also acceptable to obtain a X-ray reflective element in the present invention.

- Making additional reference to Fig. 2, a system for performing 1/5 reduction from the mask pattern M to an image on the wafer W is
30 assumable based on results of the calculations above which are

1 summarized as below:

Germanium monocrystal, (1 1 1) plane, X-ray = 5.406 angstroms,
d = 3.25 angstroms, R = 499.2 mm, i = 33.7 degrees, size of the
substrate = 50 x 50 mm, location of the X-ray source or OS = 277.2
5 mm, and location of FZP (F) or OF = 600 mm.

Industrial Applicability

This invention is concerned with X-ray lithography which has been
applied, for instance, to reproduction of a pattern for integrated
10 electronic circuits wherein presently the proximity method is
prevailed with use of a transmissive pattern mask. But this
conventional method is defective for attendant problems, for
instance, difficulty in handling of fragile masks and also
inability of dimensional reduction in imaging. For merits of
15 overcoming such difficulties with the conventional art, this
invention has potential for finding industrial applications in
such fields as noted above.

1

CLAIM(S)

1. A X-ray reflective mask element which is comprised of a X-ray reflective substrate and a X-ray mask film coated thereon, wherein
5 the substrate is worked out to have a plane face from a crystalline body which has outwardly curved X-ray diffractive structure and wherein the substrate face is cut out to have an inclination against diffractive lattice surfaces so that reflected X-ray by the Bragg's rule at center of the substrate face will travel to agree
10 with normal line assumed at the same center.

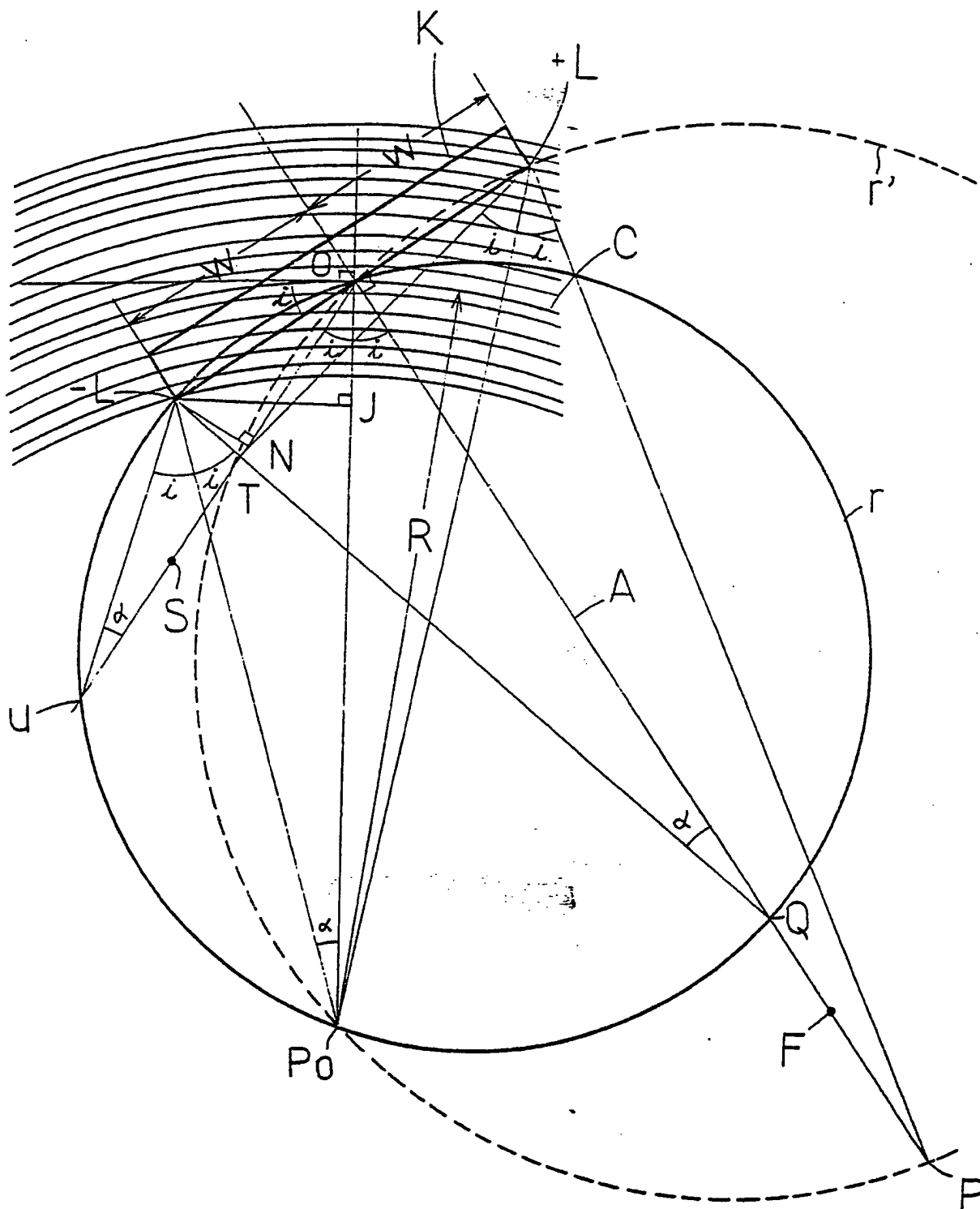
2. A system for X-ray projection and image formation, which comprises: a X-ray source; a X-ray reflective mask element which will reflect incident X-ray in conformity of the Bragg's rule so
15 that the reflected X-ray will converge to a point lying on normal line assumed on center of the mask element; and a X-ray imaging device arranged to be vertical to the substrate face at focus of the reflected X-ray.

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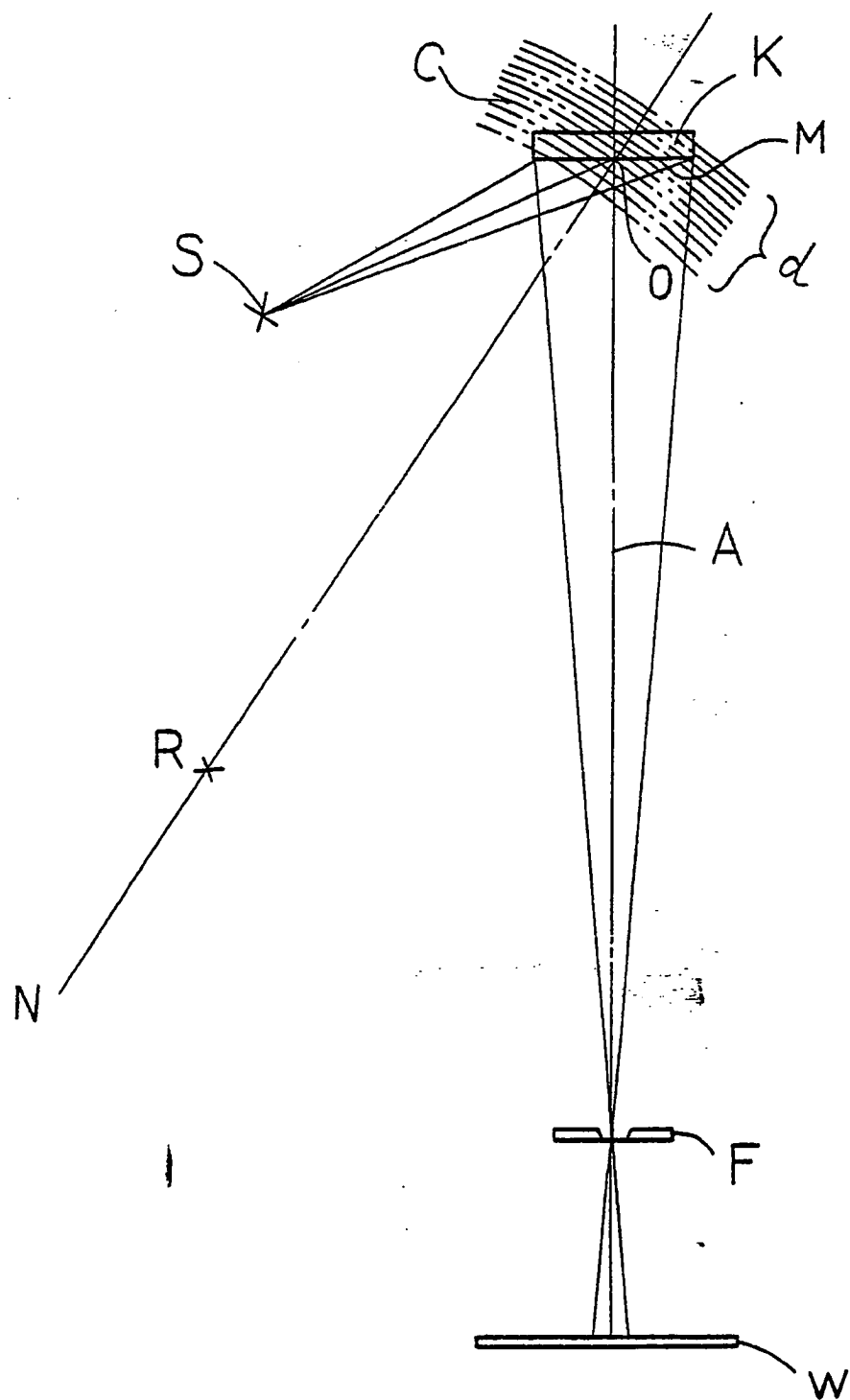
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Fig. 1



2/2

Fig. 2





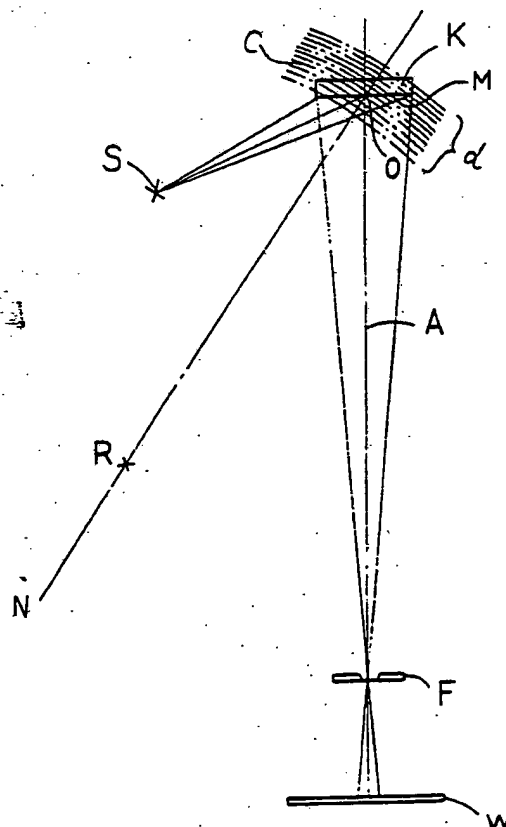
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(54) Title: X-RAY REFLECTIVE MASK AND SYSTEM FOR IMAGE FORMATION WITH USE OF THE SAME

(57) Abstract

X-ray lithography which has been applied, for instance, to reproduction of a pattern for integrated electronic circuit wherein the proximity method is prevailed with use of a transmissive patterned mask. But this conventional method is defective, for instance, in difficulty of dimensional reduction from an original pattern. In contrast, the disclosed invention overcomes such defect by introducing an X-ray reflective mask element, instead of conventional type of transmission. The reflective mask element is comprised of a crystalline substrate to reflect incident X-ray according to the Bragg's diffraction rule, which was worked out of a crystalline body having outwardly curved lattice surfaces, wherein the substrate face is formed to have an inclination against the lattice surfaces so that reflection at center of the substrate face will converge to a point on normal line assumed at the same center. Another aspect of the disclosure herein is directed to a system for X-ray projection and image formation with use of said mask element, additionally comprising an X-ray source, a Fresnel zone plate.



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INTERNATIONAL SEARCH REPORT

International Application No. **PCT/JP 87/00177**

I. CLASSIFICATION OF SUBJECT MATTER (if several classification symbols apply, indicate all)

According to International Patent Classification (IPC) or to both National Classification and IPC

IPC⁴: **G 03 F 1/00; G 03 F 7/20**

II. FIELDS SEARCHED

Minimum Documentation Searched ⁷	
Classification System	Classification Symbols
IPC ⁴	G 03 F 1/00 G 03 F 7/20

Documentation Searched other than Minimum Documentation
to the extent that such documents are included in the fields searched⁸

III. DOCUMENTS CONSIDERED TO BE RELEVANT⁹

Category ¹⁰	Citation of Document, with indication, where appropriate, of the relevant passages ¹¹	Relevant to Claim No. ¹²
Y	EP, A, 0055077 (TOKYO SHIBAURA DENKI) 30 June 1982 see the whole document	1,2
Y	Applied Physics Letters, volume 45, no. 1, 1 July 1984, American Institute of Physics, (New York, US), H. Matsumura et al.: "Demagnified projection printing by a new x-ray lithographic technique using no thin- film masks", pages 3-5 see the whole document	1,2
Y	IBM Technical Disclosure Bulletin, volume 16, no. 9, February 1974, (New York, US), R. Feder et al.: "Ultrafine line projection system", pages 3121-3122 see the whole document	1,2
Y	Patent Abstracts of Japan, volume 10, no. 19 (P-423)(2076), 24 January 1986, & JP, A, 60173551 (HIDEKI MATSUMURA) 6 September 1985	1,2

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document is combined with one or more other such docu-
ments, such combination being obvious to a person skilled
in the art

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IV. CERTIFICATION

Date of the Actual Completion of the International Search

22nd September 1987

International Searching Authority

EUROPEAN PATENT OFFICE

Date of Mailing of this International Search Report

28 OCT 1987

Signature of Authorized Officer

M. VAN MOL

III. DOCUMENTS CONSIDERED TO BE RELEVANT (CONTINUED FROM THE SECOND SHEET)

Category *	Citation of Document, with indication, where appropriate, of the relevant passages	Relevant to Claim No
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A	DE, A, 2911848 (VLSI TECHNOLOGY) 4 October 1979 see figure 12; page 21, lines 1-18 -----	1,2
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ANNEX TO THE INTERNATIONAL SEARCH REPORT ON

INTERNATIONAL APPLICATION NO. PCT/JP 87/00177 (SA 16568)

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Patent document cited in search report	Publication date	Patent family member(s)	Publication date
EP-A- 0055077	30/06/82	JP-A- 57106031	01/07/82
		US-A- 4411013	18/10/83
DE-A- 2911848	04/10/79	JP-A- 54127284	03/10/79
		US-A- 4231657	04/11/80

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